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THE SMALL-SCALE ENVIRONMENT OF QUASARS

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ABSTRACT

Where do quasars reside? Are quasars located in environments similar to those of typical L^* galaxies, and, if not, how do they differ? An answer to this question will help shed light on the triggering process of quasar activity. We use the Sloan Digital Sky Survey to study the environment of quasars and compare it directly with the environment of galaxies. We find that quasars ($M_i \leq -22$, $z \leq 0.4$) are located in higher local overdensity regions than are typical L^* galaxies. The enhanced environment around quasars is a local phenomenon; the overdensity relative to that around L^* galaxies is strongest within 100 kpc of the quasars. In this region, the overdensity is a factor of 1.4 larger than around L^* galaxies. The overdensity declines monotonically with scale to nearly unity at $\sim 1\,h_{70}^{-1}$ Mpc, where quasars inhabit environments comparable to those of L^* galaxies. The small-scale density enhancement depends on quasar luminosity, but only at the brightest end: the most luminous quasars reside in higher local overdensity regions than do fainter quasars. The mean overdensity around the brightest quasars ($M_i \leq -23.3$) is nearly three times larger than around L^* galaxies while the density around dimmer quasars ($M_i = -22.0$ to -23.3) is ~ 1.4 times that of L^* galaxies. By ~ 0.5 Mpc, the dependence on quasar luminosity is no longer significant. The overdensity on all scales is independent of redshift to $z \leq 0.4$. The results suggest a picture in which quasars typically reside in L^* galaxies, but have a local excess of neighbors within $\sim 0.1 - 0.5$ Mpc; this local density excess likely contributes to the triggering of quasar activity through mergers and other interactions.

Subject headings: Quasars: General, Galaxies: Statistics

1. INTRODUCTION

For more than two decades, significant effort has been spent attempting to understand the triggering mechanism of quasar activity, as well as the relation between quasars and their host galaxies. Since Lynden-Bell (1969), it has become widely accepted that quasars are fueled by accretion of gas onto super-massive black holes. Observations have shown that a number of nearby galaxies have a central black hole whose mass correlates with the luminosity of the spheroid of the host galaxy. This connection suggests that the formation of the black hole is linked to the formation of the galaxy which, in turn, is known to strongly depend on its environment. To develop a better understanding of the quasar phenomenon, it is therefore important to investigate and quantify the relation between quasars and their environments. Despite the importance of this issue, our knowledge of the quasar environment is still limited.

Quasar environments have been studied on different scales ranging from those of the host galaxy to those of large scales. Such studies have provided important but controversial results regarding the environment of quasars. It has been known for more than three decades that quasars are associated with enhancements in the spatial distribution of galaxies (Bahcall, Schmidt, & Gunn 1969). Studies have shown that, in the nearby universe, quasars reside in environments ranging from small to moderate groups of galaxies rather than in rich clusters (Bahcall & Chokshi 1991b; Fisher et al. 1996; McLure & Dunlop 2001).

Early observations of quasar environments (Stockton 1978; Yee & Green 1984, 1987; Boyle, Shanks, & Yee 1988; Smith & Heckman 1990; Ellingson, Green, & Yee 1991), revealed a positive association of bright quasars with neighboring galaxies at a level somewhat higher than that of normal galaxies and comparable to the environment of small- to intermediate-richness groups of galaxies (e.g., Bahcall & Chokshi 1991a). Observations of quasar environment from the Hubble Space Telescope snapshot survey (Bahcall et al. 1997) further support this density enhancement around bright quasars. All these observations focused on small scales, typically within ~ 0.5 Mpc of the quasars, and used relatively small samples of objects.

Early observations of the clustering properties of quasars themselves, as measured by the quasar autocorrelation function, suggest that quasars are significantly more strongly clustered than galaxies on scales up to 10 Mpc and greater (e.g., Shaver 1988; Shanks, Boyle, & Peterson 1988; Chu & Zhu 1988, 1989; Crampton, Cowley, & Hartwick 1989), but less clustered than rich clusters of galaxies (e.g., Bahcall & Chokshi 1991a). This finding suggests that quasars are located in high overdensity regions, more so than L^* galaxies, since higher overdensity regions are clustered more strongly than lower overdensity regions (e.g., Bahcall & Soneira 1983; Kaiser 1984; Bardeen et al. 1986). An overdense environment would indeed be expected if the quasar activity was triggered by galaxy interactions.

On the other hand, new generation surveys, such as the Two Degree Field (2dF) and the Sloan Digital Sky Survey (SDSS), have given rise to different results. Using significantly larger complete samples of quasars and galaxies, these surveys have shown that on large scales,

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i.e. from 1 to 10 Mpc, the quasar-galaxy cross-correlation and the quasar auto-correlation are comparable to the correlation function of L^* galaxies. This suggests, in conflict with previous results, that quasars and Active Galactic Nuclei (AGNs) inhabit environments similar to those of L^* galaxies (e.g., Smith, Boyle, & Maddox 1995; Croom & Shanks 1999; Croom et al. 2003; Miller et al. 2003; Kauffmann et al. 2004; Wake et al. 2004). The results also suggest that the quasar correlation function does not depend significantly on either quasar luminosity or redshift within the ranges studied.

Recent work on sub-Mpc scales using the SDSS to find quasar pairs suggests that the quasar-quasar autocorrelation function may be enhanced relative to the galaxy-galaxy distribution (Hennawi et al. 2005), consistent with the earlier results on small scales, as discussed above.

In this paper we use the SDSS survey to determine the galaxy environment around quasars as a function of scale. The SDSS is uniquely suited for this investigation: it is the largest complete survey available of both galaxies and quasars, carried out in a well-calibrated, self-consistent manner. The data used in this study covers 4000 deg^2, with $\sim 2 \times 10^3$ quasars of redshift $z \leq 0.4$ and ten million photometric galaxies to a magnitude limit of $i = 21$. We use these data to determine the mean galactic environment around quasars as a function of quasar luminosity and redshift. For comparison, the same analysis is then repeated to find the local environment around 10^5 spectroscopic galaxies in the SDSS area, as well as around random positions in the survey. All the analyses are carried out using the same ten million photometric galaxies. This technique allows a direct comparison between the environment around quasars with that around random points as well as with the environment around L^* galaxies, thereby minimizing potential selection effects and systematics.

The outline of the paper is as follows: we discuss the data in Section 2, the analysis in Section 3, and the results in Section 4. The conclusions are summarized in Section 5. Throughout this paper, we use a cosmological model with $H_0 = 70\,\mathrm{km}^{-1}\,\mathrm{Mpc}^{-1}$, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$ for both absolute magnitudes and distance measures. All distances are measured using comoving coordinates.

2. DATA

We use Sloan Digital Sky Survey (SDSS) data to determine the galactic environment of quasars and galaxies. The SDSS (York et al. 2000; Stoughton et al. 2002; Pier et al. 2003; Abazajian et al. 2003; Gunn et al. 2005) is conducting an imaging survey of 10^4 square degrees of the sky in five bands (u, g, r, i, z) (Fukugita et al. 1996; Gunn et al. 1998), followed by a spectroscopic multi-fiber survey of the brightest 10^6 galaxies and 10^5 quasars. The spectroscopic targets are selected from the high quality imaging data using well-defined selection criteria (Lupton et al. 2001; Hogg et al. 2001; Strauss et al. 2002; Richards et al. 2002). The drift-scan imaging survey reaches a limiting magnitude of $r < 23$ (Fukugita et al. 1996; Gunn et al. 1998; Lupton et al. 2001). The main spectroscopic survey targets galaxies to $r < 17.7$, with a median redshift of $z \sim 0.15$ and a tail reaching $z \sim 0.4$ (Strauss et al 2002). The spectroscopic survey of quasars , with i <19, reaches quasar redshifts out to $z \sim 5.4$. For more details on the SDSS see the above references.

The high quality imaging and spectroscopic survey of quasars and galaxies provides a unique data set for studying the environment of quasars and comparing it directly with the environment of galaxies. To do so, we use the third data release (DR3) of the SDSS spectroscopic sample of quasars (Schneider et al. 2005), selecting all spectroscopic quasars with redshift $z \leq 0.4$ and i-band Galactic extinction corrected and k-corrected magnitude $-24.2 \leq M_i \leq -22.0$ (Richards et al. 2002). We set an upper limit of -24.2 on the luminosity to avoid bright objects that may interfere with counting nearby galaxies. After applying masks for missing fields (see the end of this section), a sample of 2028 $z \leq 0.4$ quasars is used, covering an area of approximately 4000 deg^2. In addition to the quasars, we use a sample of spectroscopic galaxies as targets in our analysis so that we may compare the environment of quasars with that of galaxies. The spectroscopic galaxy sample used for comparison is the NYU-LSS sample 12 (Blanton et al. 2003b,a), which is comprised of a complete spectroscopic sample of galaxies to $i = 18.5$ corrected for both Galactic extinction and k-correction, with redshifts in the range $z \sim 0.001$ to $z \sim 0.4$. After applying masks and limiting the galaxy redshift to $0.08 \leq z \leq 0.4$ (since there are no quasars with $z < 0.08$), a sample of $\sim 10^5$ spectroscopic galaxies is available over a 2230 deg^2 area (mostly overlapping the quasar area). Our galaxy sample has a median redshift of 0.13 and a median magnitude of $M_i = -21.3$, and our quasar sample has a median redshift of 0.32 and a median magnitude of $M_i = -22.5$.

The environment of the above targets - spectroscopic quasars and spectroscopic galaxies - is then determined using the photometric galaxies from DR3 of the SDSS imaging survey. We use a sample of over 10 million galaxies with magnitude in the range $14 \leq i \leq 21$. For further comparison, we also repeat the environment analysis at approximately 10^3 random positions per target using the same method and background sample of photometric galaxies.

All samples were corrected using the same masks, which remove missing fields, missing stripes, and regions where the stripe boundaries extend beyond the extent of the photometric galaxy survey. These masks were created with SDSSpixel, a pixelization scheme routinely applied to the SDSS data[4]. We also remove all targets (i.e., quasars, spectroscopic galaxies, and random points) that are closer than 1 Mpc to the boundary or to a mask in the photometric sample in order to ensure that all targets have a complete field of photometric galaxies within the scales of interest.

3. ANALYSIS

We study the environment of the spectroscopic targets (quasars and galaxies) by determining the number of photometric galaxies within different projected radii from the quasars, from 25 kpc to 1 Mpc ($h = 0.7$). In order to normalize the density of photometric galaxies, we also estimate the density of photometric galaxies around

[4] See http://lahmu.phyast.pitt.edu/~scranton/SDSSPix/ for information on SDSSpixel

a large number of random positions in the survey area. This method allows a direct comparison of the observed density around quasars and around galaxies with that found around random positions using the same observed distribution of photometric galaxies. This latter comparison yields normalized overdensities, i.e., observed density over random density, for both the quasars and the spectroscopic galaxies. This technique then allows a direct comparison of the density of galaxies around spectroscopic targets.

Throughout the analysis, we treat all of these targets - quasars, spectroscopic galaxies, and random points - in exactly the same manner in order to provide a direct and straightforward comparison between the environment of quasars, galaxies, and random positions, and help minimize potential biases. For each of the targets, we determine the number of photometric galaxies within projected comoving radius bins from 25 kpc to 1 Mpc ($h = 0.7$). The innermost 25 kpc ($15.3''$to $3.3''$over our redshift range) is removed in all density estimations in order to avoid deblending issues at these small separations. The number of photometric galaxies observed around quasars and around spectroscopic galaxies, $N_g(Q)$ and $N_g(G)$ respectively, is divided by the same number found around random points, $N_g(R)$; these overdensities, $N_g(Q)/N_g(R)$ and $N_g(G)/N_g(R)$, are determined for each of the radii specified above. In order to account for the different redshift distributions of the $z \leq 0.4$ targets (quasars and galaxies), the overdensities are determined for each individual quasar or galaxy using the mean $N_g(R)$ appropriate for that target's redshift. All overdensities are then averaged in the relevant redshift bins, and are investigated as a function of radius, luminosity, and redshift. Our environment estimator is less sensitive to faint galaxies at high redshift, but it is still informative as we are interested in an excess in quasar environment density relative to that of galaxies. At low redshift, the average number of photometric galaxies around quasars ranges from a few galaxies within 100 kpc (typically twice the number found around random points) to ~ 100 galaxies within 1 Mpc.

In order to estimate the density errors and the correlations between different scales, we have generated 10^5 bootstrap samples of the spectroscopic quasar, galaxy and random samples, and measured the standard deviation among different realizations. As the counts of photometric galaxies are dominated by projection effects, i.e. objects uncorrelated to the spectroscopic targets, the error bars are close to Poisson errors, especially on large-scales.

4. RESULTS

Our analysis produces normalized overdensities around quasars and around spectroscopic galaxies. We note that the normalized densities we use are defined as ratios of the galaxy counts around each target relative to that around random points (e.g. $N_g(Q)/N_g(R)$); a ratio of unity implies no overdensity, i.e. the same density around quasars as around random positions. Another common definition of overdensity relative to random can be calculated using $N_g(Q)/N_g(R) - 1$. This can be directly obtained from the $N_g(Q)/N_g(R)$ ratios provided below.

The quasar overdensity is presented as a function of redshift in Figure 1 within each of our four standard

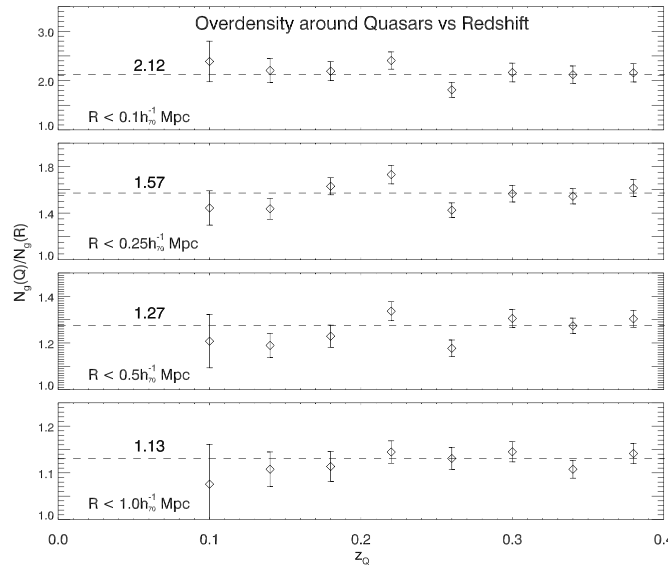

FIG. 1.— Integrated overdensity (from 25 kpc to 0.1, 0.25, 0.5, and 1.0 Mpc) around quasars ($-24.2 \leq M_i \leq -22$) as a function of redshift. The dashed line indicates the average quasar overdensity. All error bars are bootstrap errors.

radii. The mean overdensity around quasars is shown by the dashed lines. The overdensity is 2.12 within 0.1 Mpc of the quasars; i.e., the density is 2.12 times larger than the density around random points. The mean overdensity decreases monotonically with radius; it is 1.57 within 0.25 Mpc, 1.27 within 0.5 Mpc, and 1.13 within 1.0 Mpc of the quasars. This overdensity refers to the mean of all quasars with $-24.2 \leq M_i \leq -22$. The excess photometric galaxies refers to galaxies within the magnitude range $14 \leq i \leq 21$ (Section 2). The mean galaxy overdensity around quasars is independent of redshift for $z \leq 0.4$ (Figure 1).

In Figure 2 we present the overdensity as a function of luminosity for quasars and for spectroscopic galaxies within radii of 0.1, 0.25, 0.5, and 1 Mpc ($h = 0.7$). We find that, at all radii, the overdensity around galaxies (solid line) increases with galaxy luminosity. This is expected as brighter galaxies are located, on average, in higher density regions (e.g., Davis et al. 1988; Hamilton 1988; White, Tully, & Davis 1988; Zehavi et al. 2004; Eisenstein et al. 2005). The galaxy overdensity is greatest on small scales (0.1 Mpc and closer), and decreases on larger scales, as expected. The luminosity-overdensity trend is steeper on small scales than on large scales. The overdensity around L^* galaxies is 1.51 ± 0.01 times larger than random within a radius of 0.1 Mpc; the overdensity is nearly doubled, to 2.95 ± 0.05, for galaxies that are brighter by 1 magnitude.

The quasar overdensity in Figure 2 shows an increase with quasar luminosity on the smallest scales, but only for the most luminous quasars. The trend is considerably weaker than for galaxies and becomes negligible, with nearly no dependence on quasar luminosity by $\sim 0.5 - 1$ Mpc scales as well as for quasars with lower luminosities (Figure 2). This indicates that there is little or no correlation between quasar activity and environment on these larger scales, and that quasar activity is typically triggered by an interaction with a neighbor present

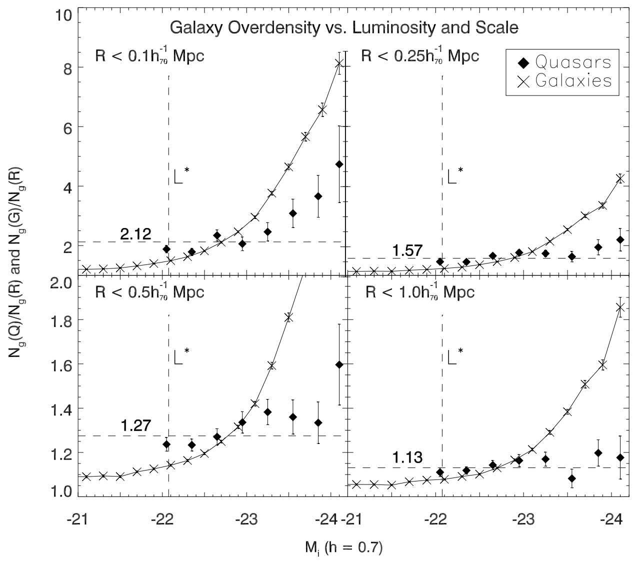

FIG. 2.— Integrated overdensity as a function of quasar or galaxy magnitude for four radii. The data are for the integrated redshift range $0.08 \leq z \leq 0.4$. The horizontal dashed line indicates the average quasar overdensity. The vertical dashed line indicates the magnitude of L^* galaxies, which we use as a standard reference for comparison with the clustering around quasars. We see that quasars on average inhabit higher local density regions than do L^* galaxies; their local environments are comparable to those of $\sim 2L^*$ galaxies.

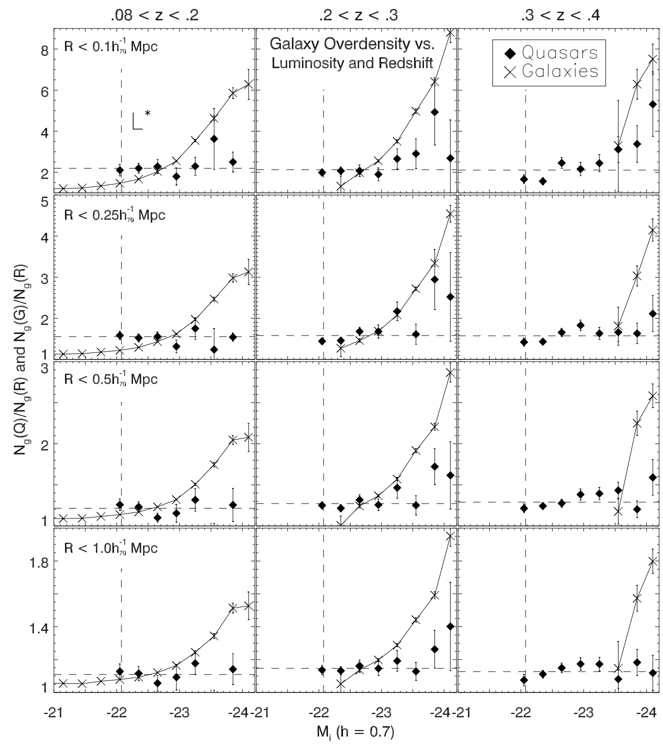

FIG. 3.— Integrated galaxy overdensity around quasars and around galaxies for our four radii (rows) as a function of seed magnitude for three redshift bins (columns).

TABLE 1
MEAN GALAXY OVERDENSITY AROUND QUASARS
($-24.2 \leq M_i \leq -22.0$, $z \leq 0.4$) AND AROUND L^* GALAXIES.

R_{max} (Mpc)	$\frac{N_g(Q)}{N_g(R)}$	$\frac{N_g(L^*)}{N_g(R)}$	$\frac{N_g(Q)/N_g(R)}{N_g(L^*)/N_g(R)}$
0.10	2.12 ± 0.08	1.507 ± 0.010	1.41 ± 0.06
0.25	1.57 ± 0.03	1.235 ± 0.004	1.27 ± 0.03
0.50	1.27 ± 0.02	1.144 ± 0.003	1.11 ± 0.02
1.00	1.13 ± 0.01	1.082 ± 0.002	1.05 ± 0.01

within ~ 100 kpc from the quasar host galaxy. The mean overdensity around quasars, $< N_g(Q)/N_g(R) >$, for all $z \leq 0.4$ quasars brighter than $M_i \leq -22$ is indicated by the horizontal dashed line in Figure 2. The mean overdensity decreases with radius. The results are summarized in Table 1.

Figure 2 allows us to compare the environment of quasars with the environment of galaxies of different magnitudes. We use the average overdensity around L^* galaxies as a standard by which to measure the quasar environment. Since quasar luminosity is clearly physically unrelated to the galactic luminosity, it should be noted that L^* galaxies are used only as an frame of reference for comparing the relative environments. We find the mean overdensity around quasars to be larger than around L^* galaxies (shown by the vertical dashed line in Figure 2) on all scales < 1 Mpc. The mean quasar overdensity is larger than the overdensity around L^* galaxies by factors that range from 1.41 ± 0.06 within 0.1 Mpc, to 1.27 ± 0.03 within 0.25 Mpc, 1.11 ± 0.02 within 0.5 Mpc, and 1.05 ± 0.01 within 1 Mpc (Table 1). (Using the alternate overdensity definition, $[N_g(Q)/N_g(R) - 1] / [N_g(L^*)/N_g(R) - 1]$, we find an excess ratio of 2.2 ± 0.16 within 0.1 Mpc decreasing to 1.6 ± 0.13 within 1 Mpc. The interpretation is, of course, the same.) The local density enhancement around quasars is similar to the local enhancement around $\sim 2L^*$ galaxies. The overdensity around quasars relative to L^* increases to a factor of 2.8 ± 0.56 closest to the quasars, at ~ 40 kpc (see below). On scales larger than 1 Mpc, the quasar overdensity becomes similar to the environment of L^* galaxies. These results indicate that quasars are located in higher density regions than are L^* galaxies, but that the overdensity exists mostly in regions very close to the quasars ($\lesssim 0.1$ Mpc), and is thus a very local excess. This local excess of galaxies near quasars likely plays an important role in triggering the quasar activity through mergers and other interactions.

These results are found to be only weakly dependent on redshift in the $z < 0.4$ range studied here. This is shown in Figure 3, where the results, similar to Figure 2, are presented for different redshift ranges. As can be seen, the trend of overdensity with quasar and galaxy luminosity remains consistent within the statistical uncertainties and no significant trend can be detected as a function of redshift. The redshift independence is further illustrated in Figure 4, where the overdensity around quasars and the overdensity around galaxies are plotted as a function of luminosity for several redshift bins. The results show a redshift independent overdensity signal for both quasars and for galaxies. (The highest luminosity galaxies, which do show some evolution, do not affect our conclusions as we compare our quasars only to L^* galaxies.) Our results for the overdensities and the comparison with the environment of L^* galaxies are unaffected by redshift.

The scale dependence of the galaxy overdensity around

spectroscopic quasars and galaxies is presented as a function of comoving distance from the target object in Figure 5. The quasar overdensities are shown for both the brightest quasars ($M_i = -23.3$ to -24.2) and for fainter quasars ($M_i = -22$ to -23.3). We find that the quasar overdensities are larger than those of L^* galaxies at all radii less than ~ 0.5 Mpc, but the overdensity increases substantially on smaller scales. The overdensities around the most luminous quasars are larger than around fainter quasars, mostly on small scales (≤ 0.1 Mpc). The lower panel of Figure 5 presents the ratio of quasar overdensity to that of L^* galaxy overdensity, as a function of scale. These data illustrate the transition between the large scales, where quasars and L^* galaxies inhabit similar environments, and the small scales, where quasars are located in higher overdensity regions than are L^* galaxies. On these small scales, the quasar overdensity is comparable to that around $\sim 2L^*$ galaxies (or brighter, for the most luminous quasars). Our results on scales greater than 0.5 Mpc are consistent with the recent SDSS and 2dF research on the large scale quasar-galaxy clustering (e.g., Smith, Boyle, & Maddox 1995; Croom & Shanks 1999; Croom et al. 2003; Wake et al. 2004), while our results on smaller scales are consistent with the early work discussed in Section 1 (e.g., Shaver 1988; Shanks, Boyle, & Peterson 1988; Chu & Zhu 1988, 1989; Crampton, Cowley, & Hartwick 1989) as well as with recent quasar-quasar pair studies (Hennawi et al. 2005). This difference in the relative quasar environment between small (≤ 0.5 Mpc) and large (≥ 1 Mpc) scales explains some of the previously contradictory results discussed in Section 1. These results suggest a picture in which quasars reside in, on average, galaxies with a luminosity comparable to $\sim L^*$, but with a local excess of neighbors within $\sim 0.1 - 0.5$ Mpc. This local excess is likely associated with triggering quasar activity.

The different galaxy densities observed for the bright and faint quasars cannot be due to gravitational lensing. The dark matter distribution in and around galaxies induce gravitational lensing effects which locally enlarge the sky solid angle and magnify the images of background objects. This effect, the magnification bias, can increase or decrease the density of distant sources around foreground galaxies depending on the variation of the number of sources as a function of magnitude (Narayan 1989). It can thus create correlations between source luminosity and foreground galaxy density. However, the amplitude of this effect is expected to be only at the percent level (Ménard & Bartelmann 2002; Jain, Scranton, & Sheth 2003) and recent observations with the SDSS have confirmed these predictions (Scranton et al. 2005). This suggests that gravitational lensing does not significantly affect our density estimations.

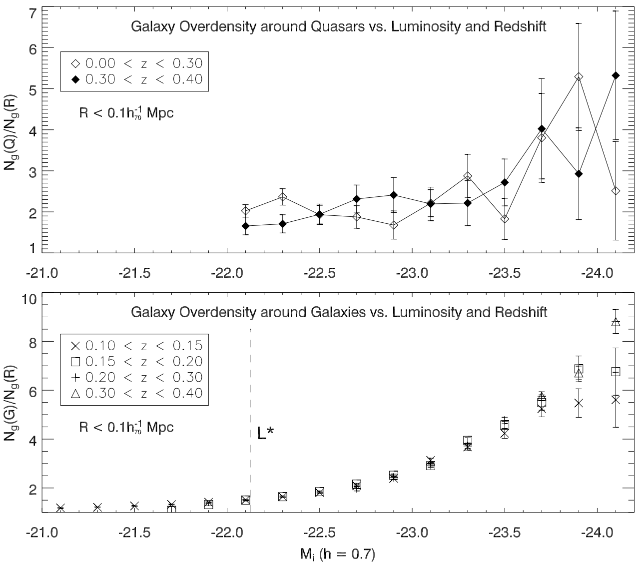

FIG. 4.— Integrated overdensity (to 0.1 Mpc) as a function of seed magnitude. Both quasars (top) and galaxies (bottom) have been separated into redshift bins. Note that there are many overlying points in the galaxy overdensity plot.

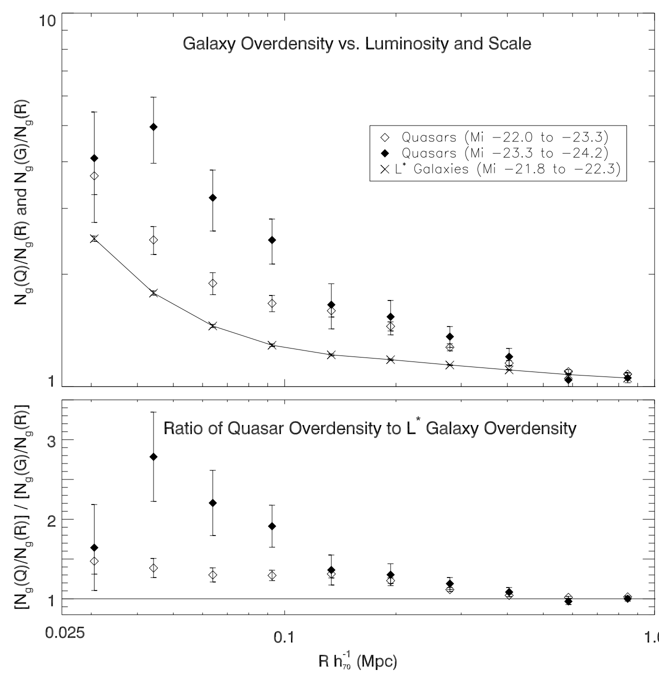

FIG. 5.— Top: Overdensity as a function of comoving radius for bright quasars, dim quasars, and L^* galaxies. L^* galaxies were defined to be within a quarter of a magnitude of the canonical value of $M_i = -22.125$. Bottom: Ratio of quasar overdensity to L^* galaxy overdensity for both bright and dim quasars. The anomalously low point for the brightest quasars at 30 kpc is the result of the brightest quasars extending beyond our 25 kpc central cut.

5. CONCLUSIONS

We use the SDSS data to investigate the local environment of quasars and compare it with the environment around galaxies and around random positions. This study provides a direct comparison between the environment of quasars and galaxies.

We use bright quasars with $-24.2 \leq M_i \leq -22$ ($h = 0.7$) and redshift $z \leq 0.4$ (2028 quasars over 4000 deg^2) to study the density of photometric galaxies with $i = 14$ to 21 (sample of $\sim 10^7$ galaxies) located within 25 kpc to 1 Mpc ($h = 0.7$) of the parent quasars. We compare the results with the same analysis carried out at random positions in the SDSS survey, $N_g(R)$; this yields the galaxy overdensity, over random, around quasars, i.e., $N_g(Q)/N_g(R)$. We investigate this overdensity as a function of quasar redshift and luminosity. The same analysis

is then repeated for determining the overdensity around 10^5 spectroscopic galaxies in the SDSS data ($i \leq 18.5$) in the same redshift range ($z = 0.08$ to 0.4). This allows a direct comparison of the quasar overdensity to the overdensity around galaxies. The overdensities are studied as a function of scale, luminosity, and redshift. This comparison of quasar environment with that of galaxies provides a self-consistent comparison of the host environments.

Our results are summarized below.

1. At all radii, from 25 kpc to ~ 1 Mpc, quasars are located in higher density environments than are L^* galaxies. The overdensity around quasars relative to that of L^* galaxies increases with decreasing scale: the overdensity is greatest closest to the quasars. At a distance of 40 kpc of the quasars, the mean overdensity for the brightest quasars ($-24.2 \leq Mi \leq -23.3$, $z \leq 0.4$) is nearly a factor of three times larger than the overdensity around L^* galaxies. The mean overdensity around the brightest quasars relative to that of L^* galaxies decreases with increasing scale to a value of 2.2 within 0.1 Mpc, 1.2 at 0.3 Mpc, and approaches unity at $\sim 0.5 - 1$ Mpc. On these larger scales, quasars reside in environments similar to those of L^* galaxies.

2. The brightest quasars are found to be located in higher overdensity regions than are fainter quasars, especially at small separations (< 0.1 Mpc). On larger scales, bright and faint quasars live in similarly dense environments.

3. The mean overdensity around quasars 0 ($< N_g(Q)/N_g(R) >= 2.12 \pm 0.08$ within 0.1 Mpc, decreasing to 1.13 ± 0.01 within 1 Mpc) is independent of redshift for $z \leq 0.4$. The mean overdensity is also independent of luminosity except for the brightest quasars, which are located in higher density environments. This dependence of quasar environment on luminosity, showing enhancement only for the most luminous quasars, is consistent with recent galaxy merging models of quasars (Hopkins et al. 2005).

4. The enhanced mean overdensity around quasars is observed to be a local phenomenon, affecting mostly the ~ 0.1 Mpc region closest to the quasars. On these scales, very close to the quasars, the high overdensity of galaxies likely affects the formation and triggering of the quasar activity through mergers and other interactions. On scales of ~ 1 Mpc, the quasars inhabit similar environments to those of normal L^* galaxies.

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